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This paper is a supplement to the paper titled "Use of Surcharges In Highway Construction" (1) by William F. Kleiman, which was presented at the June 16- 19, 1964 ASCE Soil Mechanics and Foundation Conference Design of Foundations for Control of Settlement at Evanston, Illinois. Some revisions have been made in the calculated amounts and rates of settlement and additional

16. ABSTRACT

The construction of our modern highways requires the construction of much higher embankments than were being built 10 or 15 years ago. In some instances it is impractical to avoid marsh lands or tidal flats where the foundation soils consist of weak, plastic, compressible silts and clays. Special treatment of the foundation soils and unusual construction methods not covered in the California Standard Specifications, are usually necessary to construct stable embankments in these areas. The use of berms and controlled rates of construction to assure the construction of stable embankments, as well as the use of surcharges and waiting periods to minimize the amount of detrimental settlement subsequent to paving on four State of California highway contracts are described.

Surcharges and waiting periods have been used by the California Division of Highways for a number of years. The methods used in the design and construction of embankments across four lagoons in San Diego County are presented herein. The projects, part of the Interstate Highway 5, are located from a point within the north end of the City of San Diego and extend northerly for a distance of approximately 12 miles. The construction across the lagoons where the poor foundation soil exist, covers a distance of approximately 2.7 miles.

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SURCHARGES MINIMIZE POST-CONSTRUCTION SETTLEMENT

By

William F. Kleiman

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MATERIALS & RESEARCH DEPARTMENT

SURCHARGES MINIMIZE POST-CONSTRUCTION SETTLEMENT

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SURCHARGES MINIMIZE POST-CONSTRUCTION SETTLEMENT

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SYNOPSIS

The construction of our modern highways requires the construction of much higher embankments than were being built 10 or 15 years ago. In some instances it is impractical to avoid marsh lands or tidal flats where the foundation soils consist of weak, plastic, compressible silts and clays. Special treatment of the foundation soils and unusual construction methods not covered in the California Standard Specifications, are usually necessary to construct stable embankments in these areas. The use of berms and controlled rates of construction to assure the construction of stable embankments, as well as the use of surcharges and waiting periods to minimize the amount of detrimental settlement subsequent to paving on four State of California highway contracts are described.

Surcharges and waiting periods have been used by the California Division of Highways for a number of years. The methods used in the design and construction of embankments across four lagoons in San Diego County are presented herein. The projects, part of the Interstate Highway 5, are located from a point within the north end of the City of San Diego and extend

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northerly for a distance of approximately 12 miles. The construction across the lagoons where the poor foundation soils exist, covers a distance of approximately 2.7 miles.

The soil conditions in the four lagoons are quite variable. The thickness of the soft compressible silts and clays range from 2 ft to as much as 40 ft. Interspersed with silt and clay layers are lenses or layers of fine sand ranging in thickness from less than 1 in. to 12 ft. The heights of the embankments range from 11 ft to 90 ft. The surcharges which were used range from 1 ft to 10 ft above final profile grade. The size of berms range from 6 ft high and 30 ft wide to 30 ft high and 80 ft wide. The rates of construction used were 2 ft and 3 ft per week. The waiting periods range from 60 days to as much as 3 years. The illustrations show comparisons of theoretical and observed settlements and the soil conditions at two locations in each of the four lagoons.

The amounts and rates of settlement are computed from laboratory consolidation test data. The measured amounts are within approximately 30% or less of the calculated amounts, except in one lagoon where the measured settlements exceed the predictions by approximately 70% to 80%. The measured rates are in good agreement with the theoretical rates at four locations, while at the other four locations the settlement occurred at a rate much faster than had been predicted.

It was necessary to obtain some increase in strength during construction, as well as during a waiting period prior to a second stage of construction, in order to construct the embankments to the desired heights. The rate of construction and length of waiting period as determined from time-consolidation curves and the increase in strength as determined from consolidated-quick-undrained triaxial compression test data were sufficiently accurate to permit construction of the planned embankments.

Notation - This paper is a supplement to the paper titled "Use of Surcharges In Highway Construction"(1) by William F. Kleiman, which was presented at the June 16 - 19, 1964 ASCE Soil Mechanics and Foundation Conference Design of Foundations for Control of Settlement at Evanston, Illinois. Some revisions have been made in the calculated amounts and rates of settlement and additional field settlement data are presented.

INTRODUCTION

The California Division of Highways is currently (1966) using, and has used for a number of years, surcharges or overloads and waiting periods in the construction of highway embankments. The purpose of these applications is to minimize the amount of detrimental settlement subsequent to the construction of grade separation structures, or bridges, and paving. Also, an increase in strength of foundation soils occurs during the waiting period, and this increase sometimes must be developed before a second stage of embankment construction can safely be undertaken. The amount of surcharge and the length of waiting period are dependent on the amount and rate of settlement that will occur in the foundation soils due to the added load of the embankment.

The application of soil mechanics gives reasonably accurate solutions to these problems. The reliability or safety of the final design in any foundation investigation depends, to a large degree, on the thoroughness of the soil sampling, the quality of undisturbed samples, the use of suitable test procedures[2], and, most important, a thorough analysis and proper interpretation of test data by an experienced and competent soils engineer.

The foundation soils in the lagoons discussed herein are of such poor quality that they would not support the proposed embankments without some special treatment or the application of special methods of construction. Early in the planning and preliminary investigation stages of these projects, it was proposed to strip most of the weak compressible foundation soils, dewater the areas, and build the embankments in compliance with the Standard Specifications and the ordinary construction methods. After a study of the budget schedule it was evident that a period of 4 yr or 5 yr would be available from the time of commencing the embankments until the time of final paving over the approximate 12 miles of new alignment. A study of the mass diagrams indicated that there would be a large excess of excavation on these projects. In this case it would be necessary to make provisions for disposal sites. Also, it would probably be necessary to place approximately the first foot of embankment under water, and it would be desirable to have a granular material for this purpose. Some areas in the excavation would contain suitable material for this operation and the working platform could be built with selected material from designated areas. It was decided to construct the embankments on the soft foundation soils, provide berms for stability that would utilize most of the excess excavation, and make provisions for lengthy waiting periods to minimize settlement subsequent to paving. This meant a more thorough program of sampling and testing, particularly to obtain consolidation data, than was necessary if the special treatment consisted of stripping. Papers that describe stripping and other methods of special treatment for construction of highways and soil behavior during and after construction have been presented by Root[3], and Cedergren and Weber[4].

Progressing in a northerly direction from the City of San Diego the lagoons or tidal areas[5] are named as follows: (1) Los Penasquitos Lagoon (North-East Quadrant), Station 1087± to Station 1097±; (2) San Dieguito River Basin, Station 1216± to Station 1280±; (3) San Elijo Lagoon, Station 1380± to Station 1408±; and (4) Batiquitos Lagoon, Station 1682± to Station 1725±. Due to the variable soil conditions, particularly the thickness of the soft compressible clays, and the different heights of embankment, an individual design and method of construction was used at each of the sloughs. The alignment of the new highway and location of the lagoons is shown in Fig. 1.

The embankments were designed with a safety factor just slightly above unity. Settlement platforms, piezometers, inclinometers[6] and heave stakes were installed to observe the behavior of the foundation soils during construction and the waiting periods. Data from the settlement platforms and piezometers may influence the Resident Engineer to determine when to commence a second stage of embankment construction or construction of the structures and removal of the surcharges. The heave stakes and inclinometers enable the Engineer to determine if any horizontal movement or shear failure has occurred in the foundation soils.

At one location it was necessary to provide berms which had not been planned, to assure the construction of stable embankments. At another location it was necessary to delay the start of a structure, on a second contract, approximately 2 months. Field settlement data indicated that settlement was not complete after the recommended 1-yr waiting period following a grading contract. The soil conditions, design of embankment and subsequent construction in each of the lagoons are presented below.

METHODS OF ANALYSIS

Settlement: The one-dimensional theory of consolidation as set forth by Terzaghi and Peck(7) and also as presented by Taylor(8), is used to estimate the amount and rate of settlement. The formula for calculating the amount of settlement is:

$$2H_s = 2H \frac{e_o - e_f}{1 + e_o} \quad \text{when}$$

$2H_s$ = amount of settlement

$2H$ = thickness of compressible layer,

e_o = the in-place void ratio of the material when loaded with pressure equal to the existing overburden pressure, and

e_f = the void ratio of the material due to additional pressure (embankment).

Due to the depth and thickness of the compressible layer in relation to the width and height of the embankment, it is assumed that the total pressure of the embankment is effective throughout the total thickness of the compressible layer. Fig. 2 shows the pressure-void ratio curve representative of the very soft clay layer in the San Dieguito River Basin, Station 1278+50. The measured settlement at this location is shown on Fig. 7.

The time for a given degreee of consolidation varies directly with the square of the length of the drainage path and inversely with permeability of the soil. The Logarithm of Time Fitting Method presented by Taylor(8) is used on routine investigations. The time for 50% consolidation of a laboratory specimen can be determined from the time-consolidation curves and the time for 50% settlement in the field is calculated by the following formula:

$$T_{50} = \frac{H^2 \quad t_{50}}{h^2} \quad \text{when}$$

T_{50} = time for 50% settlement in the field,

t_{50} = time for 50% consolidation of laboratory specimen,

H = length of drainage path in the field, and

h = length of drainage path in laboratory specimen.

The value of t_{50} is usually the average obtained from several time-consolidation curves. The presence of sand layers validates the assumption of double drainage in the field and the time for various percentages of settlement in the field is obtained by the use of the time factors presented by Taylor(8). The time-consolidation curves for the very soft clay in the San Dieguito River Basin at Station 1278+50 are shown on Fig. 3.

Stability: The well-known graphical stability analysis, presented by Taylor(8) and based on the Swedish circular arc failure surface and the method of slices developed by Fellinius are used to determine the safe height of embankments. The stability of the embankment is proportional to the forces tending to resist sliding and the forces tending to produce sliding. These forces are summed up in the formula to caculate safety factor as follows:

$$S.F. = \frac{\Sigma N \tan \phi + cL}{\Sigma T} \quad \text{when}$$

S.F. = safety factor,

ΣN = summation of normal forces acting on potential slip plane,

Tan ϕ = tangent of angle of internal friction of the soil,

c = cohesion of the soil,

L = arc length of potential slip plane, and

ΣT = summation of tangential forces acting on potential slip plane.

The in-place strength of the foundation soils, cohesion, and angle of internal friction, which are used in the stability analysis, are obtained from unconfined compression and quick-undrained triaxial compression tests. The increase in strength due to consolidation is determined from consolidated-quick-undrained triaxial compression tests. The rate at which this increase occurs can be determined from the time-consolidation curves and a study of the soil profile, the gradation of the compressible material, and other factors. Because of the many indeterminate factors used in rate studies a great deal of sound engineering judgment is used to determine a rate of construction and length of waiting period to minimize settlement subsequent to paving. Quite often, when the stability analysis indicates a safety factor of approximately unity, a controlled rate of loading is recommended. This will tend to increase the safety factor and will give the Resident Engineer the opportunity to observe the behavior of the foundation soils during construction.

Field Conditions: Selected material was used to construct a working platform across the unstable foundation areas. This material was obtained from designated areas in the roadway excavation. The working platform was constructed by dumping successive loads in a uniformly distributed layer of a thickness necessary to support the equipment while subsequent layers were placed at the specified rate and compaction. The settlement platforms were installed as soon as practicable after placement of the working platform. They were installed on the centerline of the embankment, where the maximum amount of settlement would occur.

In some instances, the soil profiles shown on Fig. 4 - 11 may indicate rather shallow exploration for the height of embankments presented herein. Many other borings were made along the alignment, and they showed considerably more depth of sand.

SOIL CONDITIONS, ANALYSIS, DESIGN AND CONSTRUCTION

Example No. 1 - Los Penasquitos Lagoon

The new highway alignment crosses approximately 1000 ft of this lagoon, Station 1087± to Station 1097±. The original ground is relatively flat at approximately Elevation 6. The area is slightly beyond tidal limits, but the water table is usually only a few feet below the ground surface. Sometimes water, from rain and run-off from surrounding hills, tends to impound in this flat area. The height of the mainline embankment ranges from approximately 12 ft to a maximum of approximately 23 ft. The embankments for frontage roads and ramps range in height up to 18 ft.

The preliminary investigation revealed the foundation soils to consist of layers, 4 ft to 12 ft thick, of very soft to soft silt and clay, with lenses or layers of sand or silty sand. The weak compressible clays are mainly in the upper 10 ft to 20 ft of depth, and these plastic materials are underlaid by relatively dense sand. Some of the borings revealed clay at the surface and others revealed sandy surface material underlaid by the soft clay.

The results of unconfined compression tests on the clay indicated in-place shear strength on the order of 150 lb per sq ft to 240 lb per sq ft. The stability analyses indicated that not more than 5 ft or 6 ft of stable embankment could be built without some special treatment or precautions during construction.

The consolidation test data indicated that settlements on the order of 1 ft to 2 ft could be expected. Due to variations in the thickness of the clay layers, differential settlements within the lagoon might be as much as 1 ft. The amount of settlement, after a waiting period of 2 yr or 3 yr, might be not more than 1/2 ft. The use of a surcharge would shorten the waiting period and minimize the amount of settlement subsequent to construction. Time studies and stability analyses showed that the embankments could be built without serious failures with the use of berms and a controlled rate of loading.

The Special Provisions specified that the embankments should be built at a controlled rate not to exceed 2 ft of embankment per wk. The embankments were built to a surcharge height of 4 ft above profile grade. The size of the berms varied with the height of the embankment, but generally were on the order of 8 ft high and 40 ft wide. Construction of the embankments was begun in August, 1962, and completed in February, 1963; surcharge was removed in June, 1965, and paving was completed in January, 1966.

The amounts of settlement that have occurred at two locations are shown on Fig. 4 and Fig. 5. The theoretical time-settlement curves are corrected for construction and are considered to be in very good agreement with the actual measured settlement. The theoretical curve and the amount shown for the calculated ultimate is based on the amount of embankment to surcharge height of 4 ft above profile grade. The amount of measured settlement is 8% more at Station 1095 and 29% less at Station 1096 than the calculated ultimate. The time curves are leveling or have leveled, and it is anticipated that the settlement subsequent to paving will be negligible.

Example No. 2 - San Dieguito River Basin

The river basin is approximately 6400 ft wide, Station 1216± to Station 1280±. The basin is filled with typical marsh land soils of soft silts and clays, with loose sand extending to depths of 30 ft or more. The elevation of original ground is approximately 10 ft at the south and north sides of the river basin and approximately 2 ft near the center. Over these soft soils, the height of embankment is approximately 90 ft at the south side, sloping down to approximately 16 ft near the center, and increasing to approximately 52 ft at the north side of the basin. The San Dieguito River Bridge is located near Station 1248, and the Via De La Valle Overcrossing is located in the vicinity of Station 1277.

Unconfined compression and quick-undrained triaxial compression tests showed shear strength of approximately 300 lb per sq ft for the soft foundation soils. Time studies indicated that some increase in strength could be expected during construction. The stability analyses indicated that with the increase in strength due to settlement during construction, approximately 30 ft of embankment could be constructed.

Calculations indicated that settlement on the order of 3 ft could be anticipated under embankments of 80 ft or 90 ft height near Station 1224; approximately 1/2 ft of settlement would occur in the center of the river basin; and approximately 5 ft would occur under 50 ft of embankment on the north side of the basin, vicinity of Station 1278.

The conclusions of the complete analysis were: (1) with a controlled rate of loading and the use of berms the embankment could be built to a maximum height of 60 ft; (2) the berms should be 1/2 the fill height with a maximum height of 30 ft and they should be 80 ft wide; (3) in order to assure some increase in strength during construction, the embankments should be built at a rate not in excess of 3 ft per wk, and after a height of 60 ft provisions should be made for a waiting period of 1 yr; (4) the second stage of construction should also be controlled at a rate of 3 ft per wk; (5) a surcharge of 1 ft to 2 ft should be placed between Station 1216 and Station 1276 and a surcharge of 10 ft should be used in the vicinity of Station 1224 and a period of 3 yr in the vicinity of Station 1278 would reduce the amount of settlement subsequent to paving to a negligible quantity.

The first stage construction was begun in March, 1962, and completed in November, 1962. Construction of the second stage of embankment between Station 1205± and Station 1228± began on November 8, 1963. The surcharge was removed during August, 1965, and paving was completed in January, 1966.

The settlement at Station 1224, and at Station 1278+50 where the 60 ft of embankment includes a surcharge of 10 ft above profile grade, is shown on Figs. 6 and 7, respectively. In one case (Fig. 6) the actual amount of settlement is approximately 5% less than the calculated ultimate. In the other case (Fig. 7) the calculated ultimate is approximately 26% more than the actual measured settlement as of January 11, 1966. The measured settlement curves show a decreasing rate of settlement during the 1-yr waiting period. At Station 1224, the actual rate is in fair agreement with the theoretical rate during construction to the height of 60 ft, and the difference between the two curves is decreasing during the waiting period. The settlement curve also shows the expected increase in settlement during the second stage of construction, and there is excellent agreement after this second stage. At Station 1278+50 the two curves cross and there is a slight increase in the rate of settlement near the end of the waiting period. Construction operations for the Via De La Valle Overcrossing at this location were delayed 2 months to allow more time for settlement, but this did not delay the overall completion of the contract. Some settlement did occur during the waiting period after construction of the structure. The abutments for this structure are set on spread footings in the embankment and provisions have been made for jacking or raising the bridge deck, as necessary, to maintain a smooth profile from structure to embankment. The settlement curves indicate that the scheduling of construction, with the use of surcharges and waiting periods will assure a tolerable amount of settlement after paving.

Example No. 3 - San Elijo Lagoon

The new embankment crosses approximately 1500 ft of this lagoon, Station 1381± to Station 1400±, and a bridge for crossing the waterway and Manchester Avenue is located in the vicinity of Station 1396. The height of embankment to profile grade is 67 ft at Station 1383 and slopes down to a height of 33 ft at Station 1400. The elevation of the ground is approximately +2. An earth dike near the mouth of the channel prevents flooding during high tides, but the area does become flooded by rain and surface runoff from surrounding hills.

The soils investigation showed a surface layer, 3 ft to 6 ft thick, of soft to very soft, moderately compressible, highly plastic clay with a minor amount of organic material. The clay is underlaid by loose to dense silty sand or sand. Only one boring, out of a total of 13, showed a surface layer of sand above the clay. Laboratory strength tests indicated in-place shear strength on the order of 100 lb to 150 lb per sq ft for the very soft clay. It was immediately apparent that this material would not support even the minimum height of embankment without some special treatment and precautions during construction. However, the material would consolidate quite rapidly, and some increase in strength during construction would permit placement of a stable embankment to a height of approximately 20 ft. These soil conditions are such that it would probably be ideal to use the stripping method as a means of special treatment, but the budgeting of this and connecting projects would allow a period of 4 yr or 5 yr from the start of construction to final paving.

Stability analyses and time studies indicated that if berms 20 ft high by 50 ft wide are used, and if the embankment were built at a controlled rate not to exceed 2 ft per wk, a stable embankment could be built to a maximum height of 50 ft. The time studies indicated that it would be necessary to make provisions for a waiting period of 60 days in order to obtain the strength necessary for construction of the embankment to final grade. Calculations indicated that approximately 1½ ft of settlement could be anticipated. A surcharge of 2 ft above profile grade, mainly to compensate for settlement, and a waiting period of 90 days, would result in a negligible amount of settlement subsequent to paving.

The contract for construction of the embankment across San Elijo Lagoon included the embankment across Batiquitos Lagoon, which will be discussed later, and also included construction of the San Elijo Bridge. This contract was awarded in August, 1961, and completed in May, 1963. A contract which includes several structures, paving across San Elijo, and several miles of new freeway construction was advertised in December, 1963. The paving operations were completed February, 1965, and this portion of road was open to traffic in June, 1965.

The settlements, which have occurred under 69 ft and 62 ft of embankment in San Elijo Lagoon are shown on Fig. 8 and 9, respectively. These are examples of the least accurate estimates of settlement, as at both locations the amount of measured settlement is approximately 70% greater than the calculated ultimate, and the settlement has occurred in approximately 1/2 the time calculated from the laboratory consolidation test data. The satisfying feature of the measured settlement curves is that they show a decrease in the rate of settlement during the waiting period after construction to a height of 50 ft, an increase in the rate of settlement during the second stage of construction to surcharge height of 2 ft above profile grade, and they show a very slow rate of settlement during the second waiting period. These data definitely show that the settlement subsequent to paving should be negligible.

Example No. 4 - Batiquitos Lagoon

The marsh is approximately 4000 ft wide at this location, Station 1685± to Station 1725±, and two structures have been constructed within these limits. The La Costa Avenue Overcrossing is located in the vicinity of Station 1689±, and the Batiquitos Bridge is located in the vicinity of Station 1716±. The maximum height of the approach embankments to the overcrossing is approximately 39 ft. The mainline embankment is approximately 15 ft high in the vicinity of the overcrossing, slopes down to a height of approximately 12 ft near the middle of the lagoon and increases to a height of 40 ft on the north side. The elevation of original ground, similar to the other lagoons, is approximately +1 or +2. As at San Elijo Lagoon, poor drainage conditions cause flooding of the area during and after periods of rain.

The very weak compressible clay soils extend to a maximum depth of approximately 20 ft and are interspersed with lenses of loose sand and peaty material. The preliminary investigation revealed dense sand in the bottom of all borings. The in-place strength of the soft mud, as indicated by unconfined compression and quick-undrained triaxial compression tests, was on the order of 100 lb to 150 lb per sq ft. Time studies and stability analysis indicated that berms, a controlled rate of loading, and two-stage construction would be necessary to build stable embankments to the planned heights. Calculations indicated that settlement on the order of 3 ft to 4 ft could be anticipated. Time studies and examination of the soil profiles showed that the rate of settlement within the lagoon would be highly variable, due to the difference in thickness of the clay layers and the alternating layers or lenses of sand and silty sand. In some areas noticeable settlement would occur 2 yr or 3 yr after construction. Berms and loading at the rate of 2 ft per wk would permit construction to a height of 25 ft in the first stage. The berms would have to be 12 ft high and 50 ft wide in order to build to the planned profile grade plus some surcharge.

The construction of the embankments was commenced during August, 1961, and was completed in May, 1963. The Special Provisions specified a rate not to exceed 2 ft in height per wk. Provisions were made for a waiting period of 180 days after construction to a height of 25 ft. This period would be necessary to obtain the increase in strength of the foundation soils necessary for the second stage of construction, at the same controlled rate of loading. The embankments were built to a surcharge height of 10 ft above profile grade in the vicinity of the overcrossing. The time-settlement studies indicated that if the surcharge remains in place for a period of 2 yrs, the settlement subsequent to construction will be negligible. The contract for construction of the structures and paving was let in December, 1964; the surcharge was removed during March, 1965, and the actual paving was done in November, 1965. The contract will be completed about August, 1966. Typical settlement curves and soil data for Batiquitos Lagoon are shown on Figs. 10 and 11. The curves indicate that the amount of actual settlement will be very close to the calculated ultimate figure. At Station "LC-2" 1687+50 the actual rate of settlement is faster than the theoretical rate whereas at Station "LC" 1693+50 there is good agreement between the actual and theoretical rates, especially during the first stage of construction. The curves show the expected leveling-off during the waiting periods and give good evidence that the settlement after paving will cause very little distortion of the pavement profile.

This is the one lagoon where some minor mud waves or shear failures occurred during the placement of the working platform. Some berms, which were not planned, were placed to assure stability of the embankment. Quaking or sponginess was noticeable during construction in the area where the berms were added. Some cracking appeared in the embankment after the first stage of construction. A careful field review and study of the settlement data indicated that the cracks were probably due to differential settlement and the sandy embankment material cracking at relatively low strain. The embankment appeared stable at the end of the waiting period. The second stage was constructed as planned and there was no delay in completion of the contract.

SUMMARY

The construction of highways across marsh lands or tidal flats usually requires some special treatment of the foundation soils and unusual construction methods. Stripping of the soft compressible soils, sand drains and stage construction with surcharges and waiting periods are among the methods that are often considered and investigated by the California Division of Highways.

The choice of method of construction is determined only after a thorough foundation investigation, economic comparisons of several alternates, estimates of costs of maintenance and reconstruction, and the total period of time available for the construction. The principles of soil mechanics are used to predict the behavior of foundation soils during and after construction.

Laboratory consolidation test data are used to predict amounts and rates of settlement that will occur in foundation soils when loaded with highway embankments. The safe height to which embankments can be built without precautions during construction is determined from unconfined and quick-undrained triaxial compression test results. Berms are used to construct the embankments to greater heights. Time-consolidation curves, consolidated-quick-undrained triaxial compression test data, and sound engineering judgment are the basis for determining a safe controlled rate of loading in order to construct the embankments to still greater heights.

Experience in California has shown that reasonably accurate estimates of the amounts of ultimate settlement due to consolidation of fine-grained soils can be made. Predictions of the rates of settlement are less reliable because of the many indeterminate factors used in time studies and the actual observed rates do not always agree with the calculations.

The use of surcharges and waiting periods on approach embankments to structures is becoming common practice in the construction of California highways. They are also used in construction across marsh lands where after-paving settlement of the foundation soils would cause distortion of the finished profile and damage to or destruction of the pavement.

Comparison of measured settlement and predicted settlement at two locations in each of four lagoons in San Diego County, California, has been presented. There is "good" or "very good" agreement between the actual and theoretical rates in four instances especially during construction and early in the waiting period. In the other four instances the actual rate is much faster than the calculated rate. The measured amount of settlement exceeds the calculated amount by only 8% at two locations. At four locations the measured amount ranges from 5% to 29% less than the calculated amount; and at the other two locations, in San Elijo Lagoon, the measured amount of settlement is approximately 70% to 80% more than the theoretical amount.

The projects described herein are good examples of the benefits that can be obtained from the use of surcharges and planned waiting periods. The actual field measurements are as close to the theoretical predictions as can be expected in these areas where the thickness of the soft silts and clay, interspersed with layers or lenses of loose sand, is quite variable within any one lagoon. The recorded settlements furnish good evidence that the settlement sbusequent to paving will not be detrimental to the riding qualities of the finished roadway.

Paving has been completed across the lagoons for periods of two months to eleven months, as of March, 1966, and it is planned to open approximately 20 miles of new Interstate Highway 5 to traffic this summer. A field review of this alignment was made in March 1966, and although the pavement has been completed for a relatively short time, there is no evidence of distress due to unforeseen settlement.

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FIGURE CAPTIONS

Fig. 1 Location Map

Fig. 2 Typical Pressure-Void Ratio Curve, soft silty clay, San Dieguito River Basin, Station "SD" 1278+50.

Fig. 3 Typical Time-Consolidation Curves, soft silty clay, San Diéguito River Basin, Station "SD" 1278+50.

Fig. 4 Settlement at Los Penasquitos Lagoon, Station "SD" 1095.

Fig. 5 Settlement at Los Penasquitos Lagoon, Station "CV-3" 1096.

Fig. 6 Settlement at San Dieguito River Basin, Station "SD" 1224.

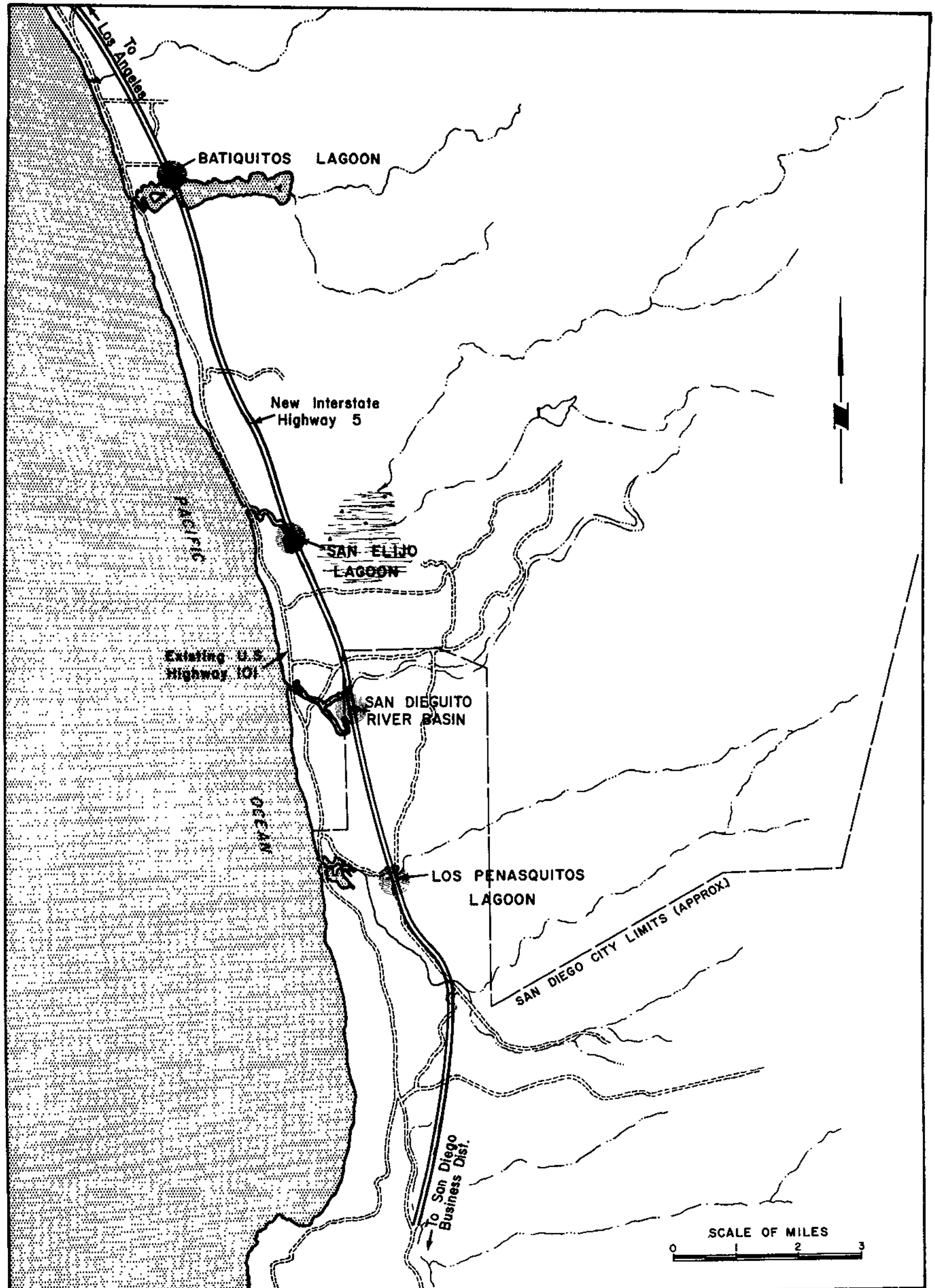
Fig. 7 Settlement at San Dieguito River Basin, Station "SD" 1278+50.

Fig. 8 Settlement at San Elijo Lagoon, Station "A" 1383+50.

Fig. 9 Settlement at San Elijo Lagoon, Station "A" 1386.

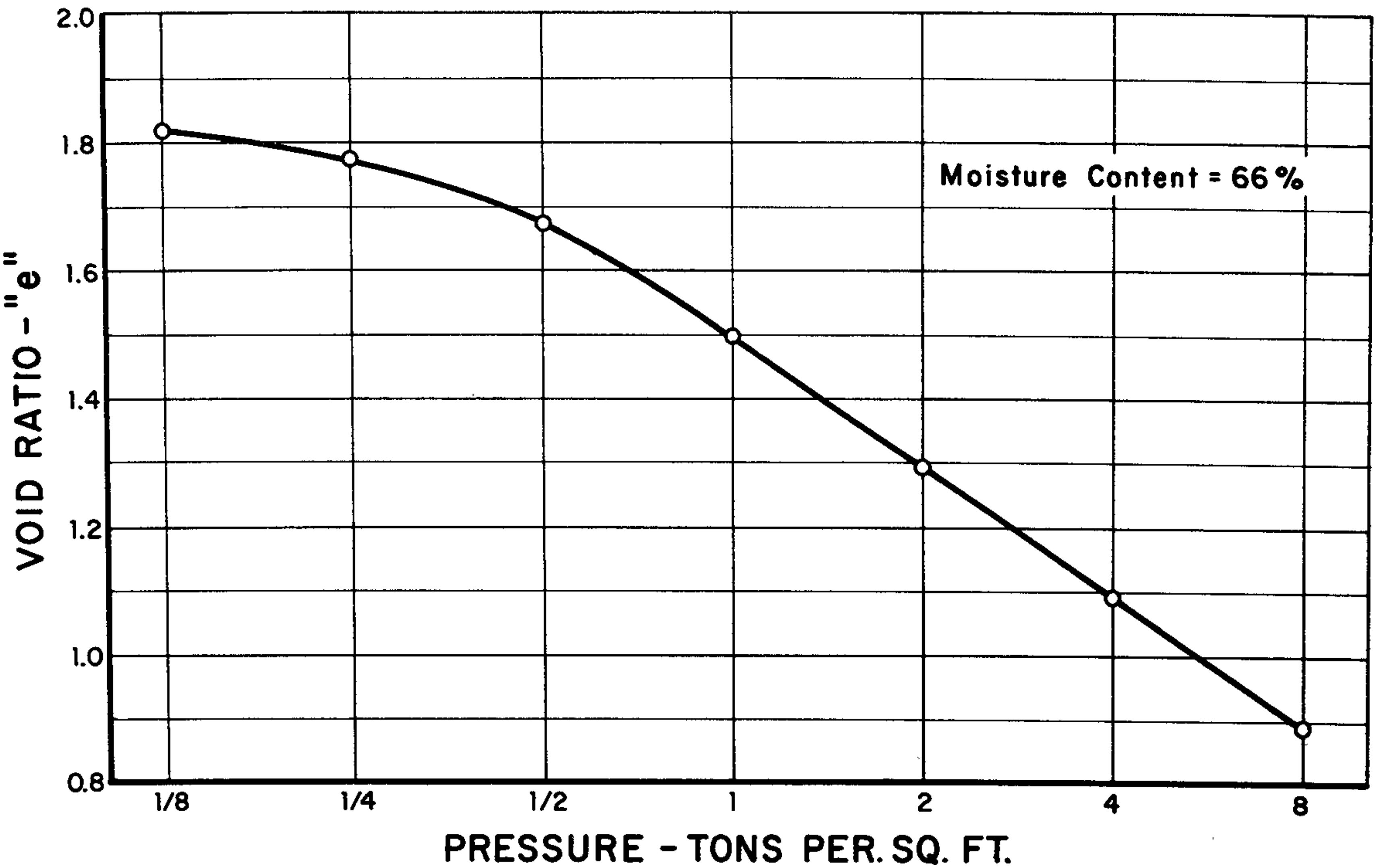
Fig. 10 Settlement at Batiquitos Lagoon, Station "LC-2" 1687+50.

Fig. 11 Settlement at Batiquitos Lagoon, Station "LC" 1693+50.

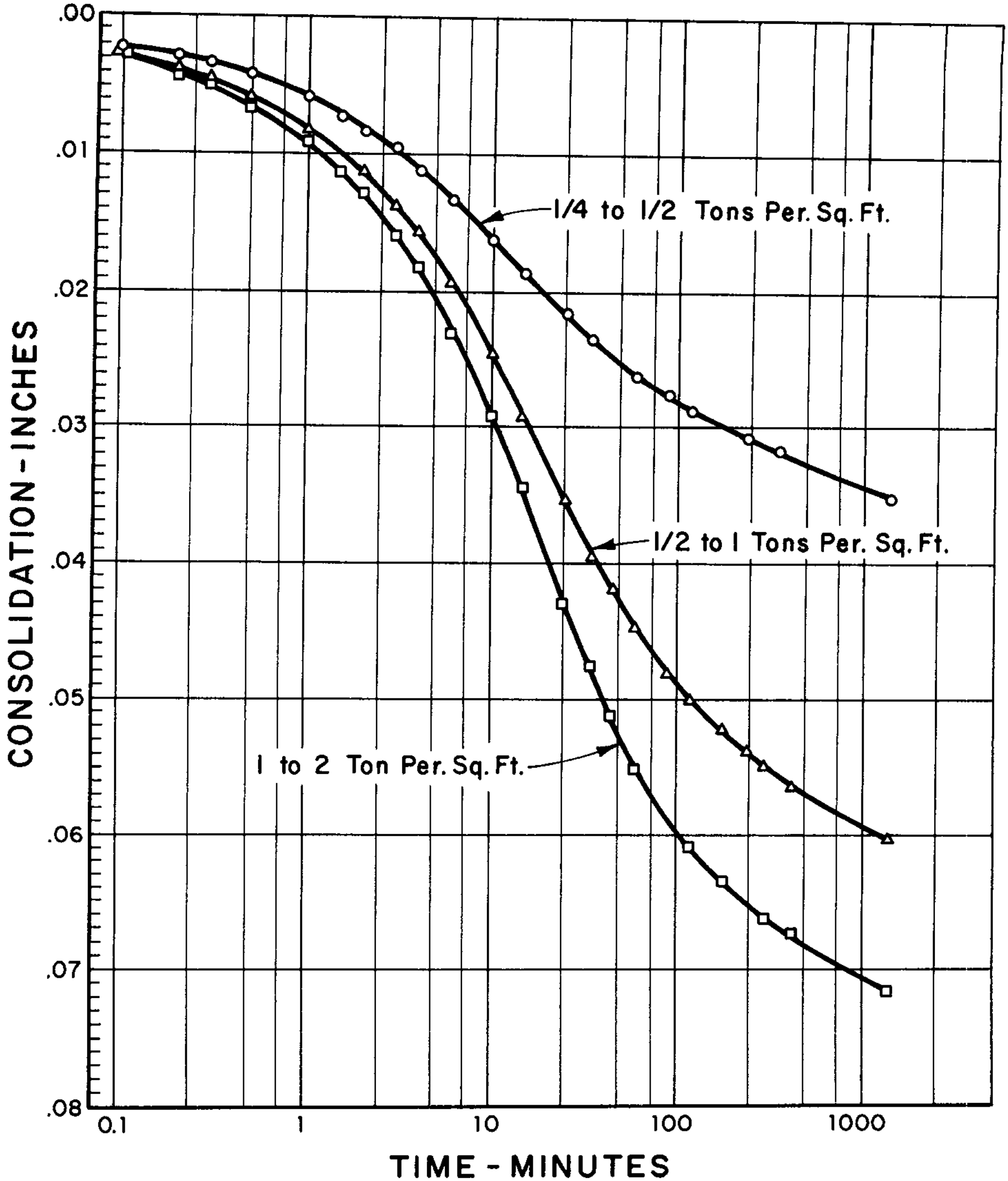


LOCATION MAP

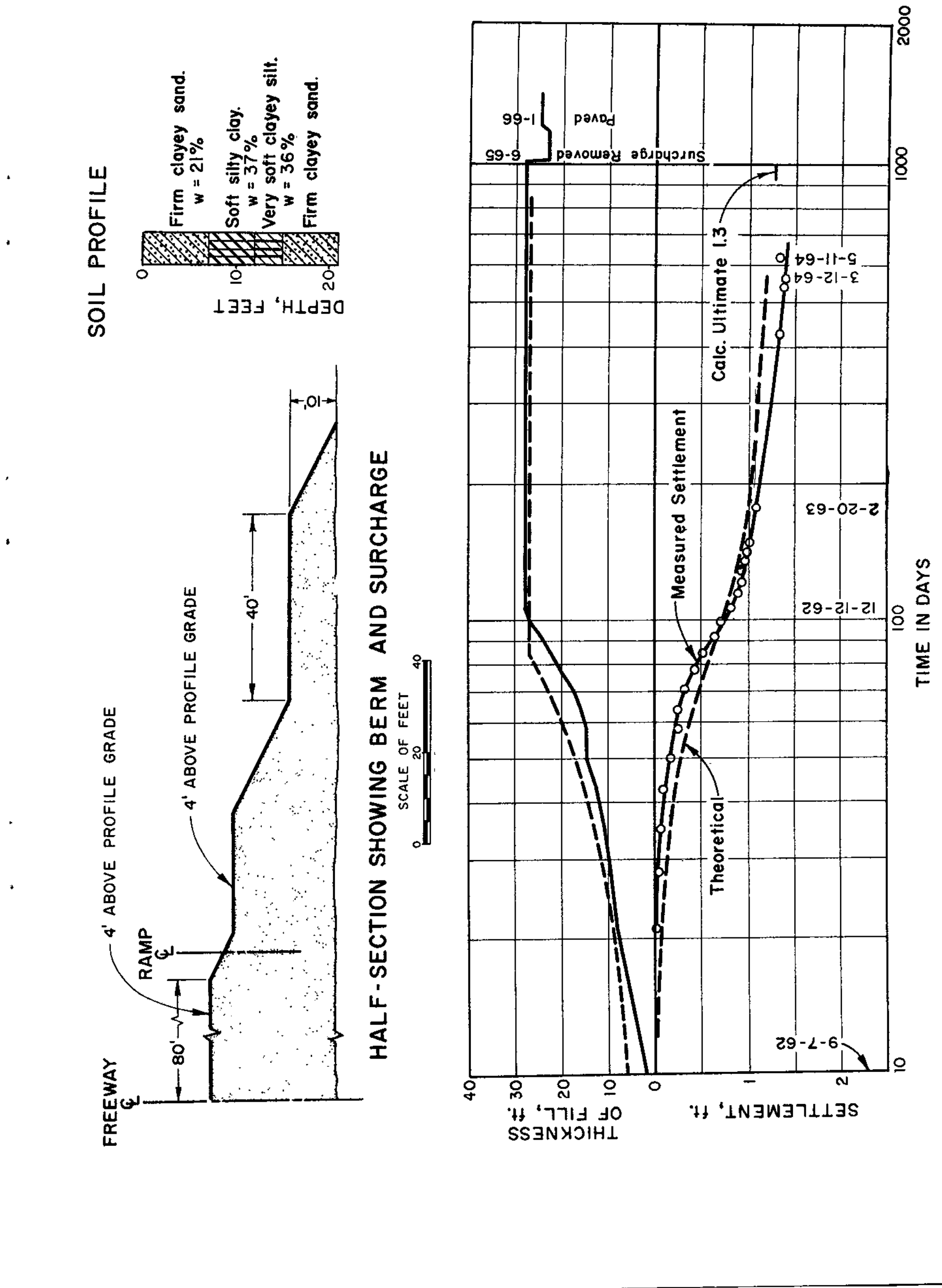
FIGURE 2



TYPICAL PRESSURE-VOID RATIO CURVE, SOFT SILTY CLAY
SAN DIEGUITO RIVER BASIN, STATION "SD" 1278+50

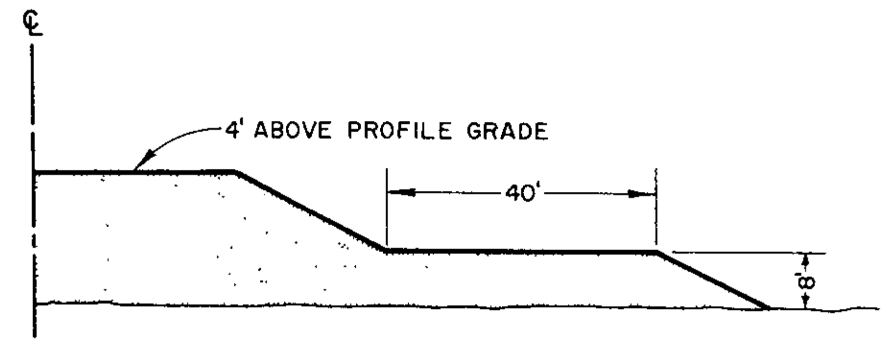


TYPICAL TIME-CONSOLIDATION CURVES
SOFT SILTY CLAY, SAN DIEGUITO RIVER BASIN
STATION "SD" 1278+50



SETTLEMENT AT LOS PENASQUITOS LAGOON
STATION "SD" 1095

FIGURE 5

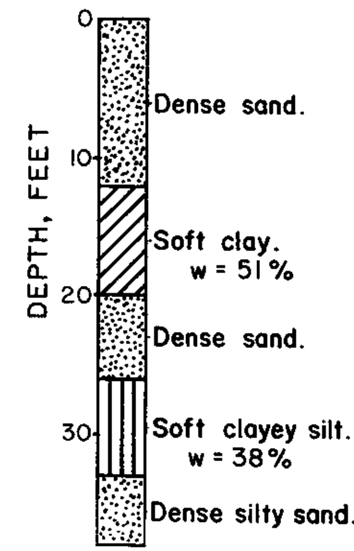


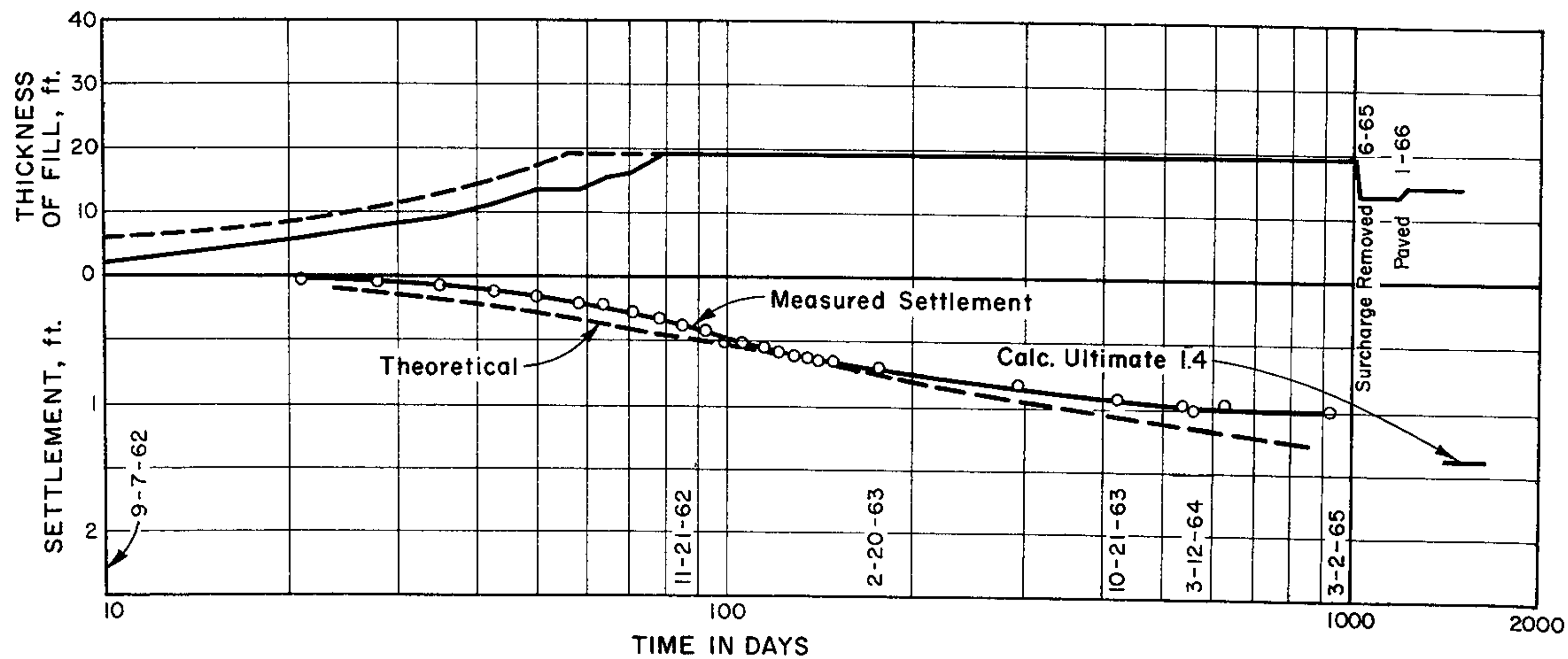
HALF-SECTION SHOWING BERM AND SURCHARGE

SCALE OF FEET

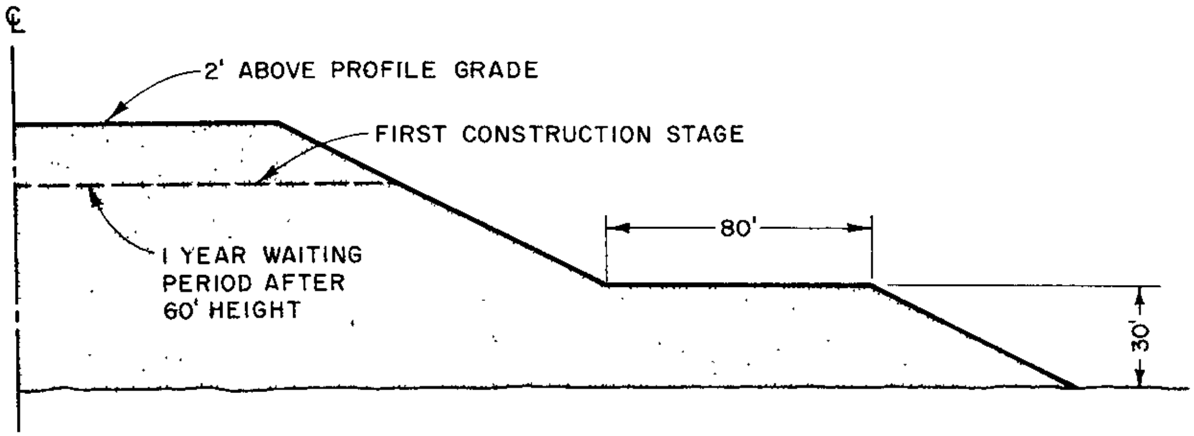
0 20 40

SOIL PROFILE





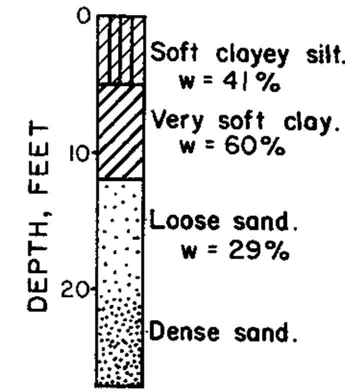
SETTLEMENT AT LOS PENASQUITOS LAGOON
STATION "CV-3" 1096

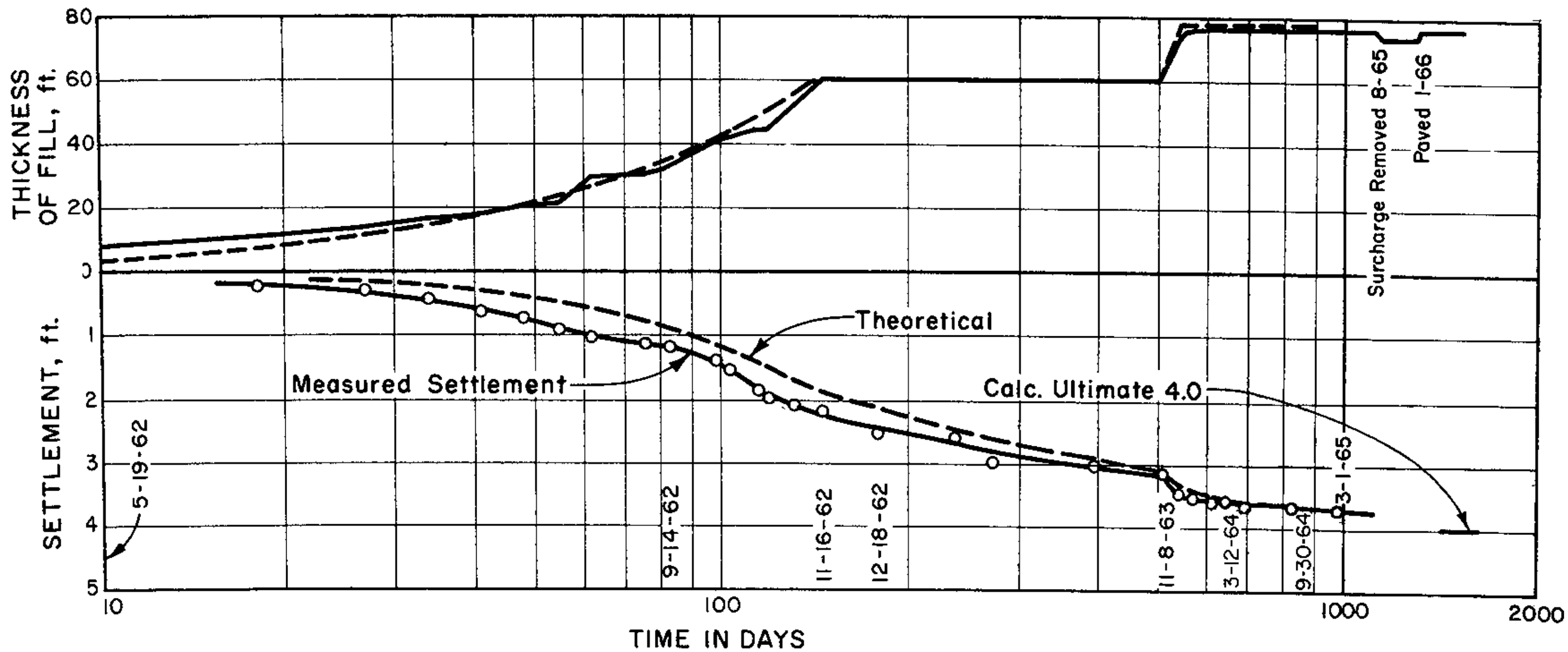


HALF-SECTION SHOWING BERM AND STAGE CONSTRUCTION

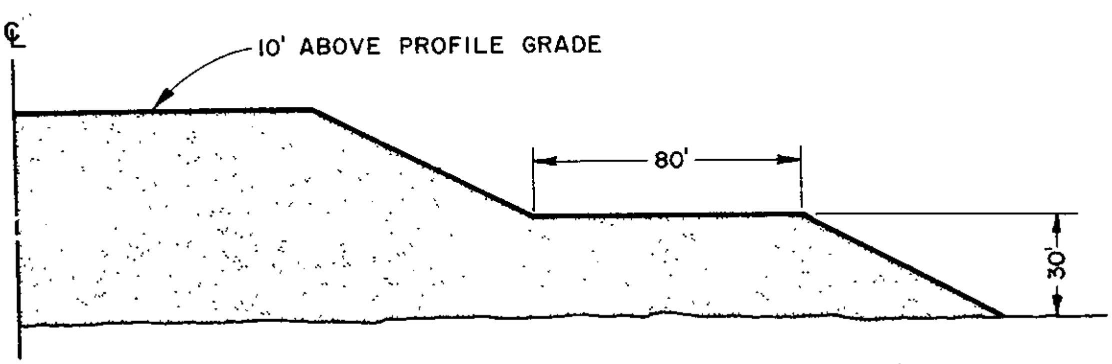
SCALE OF FEET
0 40 80

SOIL PROFILE





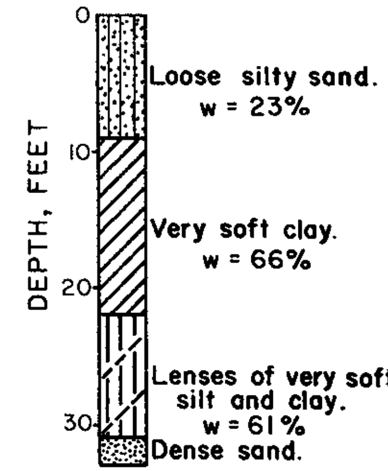
SETTLEMENT AT SAN DIEGUITO RIVER BASIN
STATION "SD" 1224

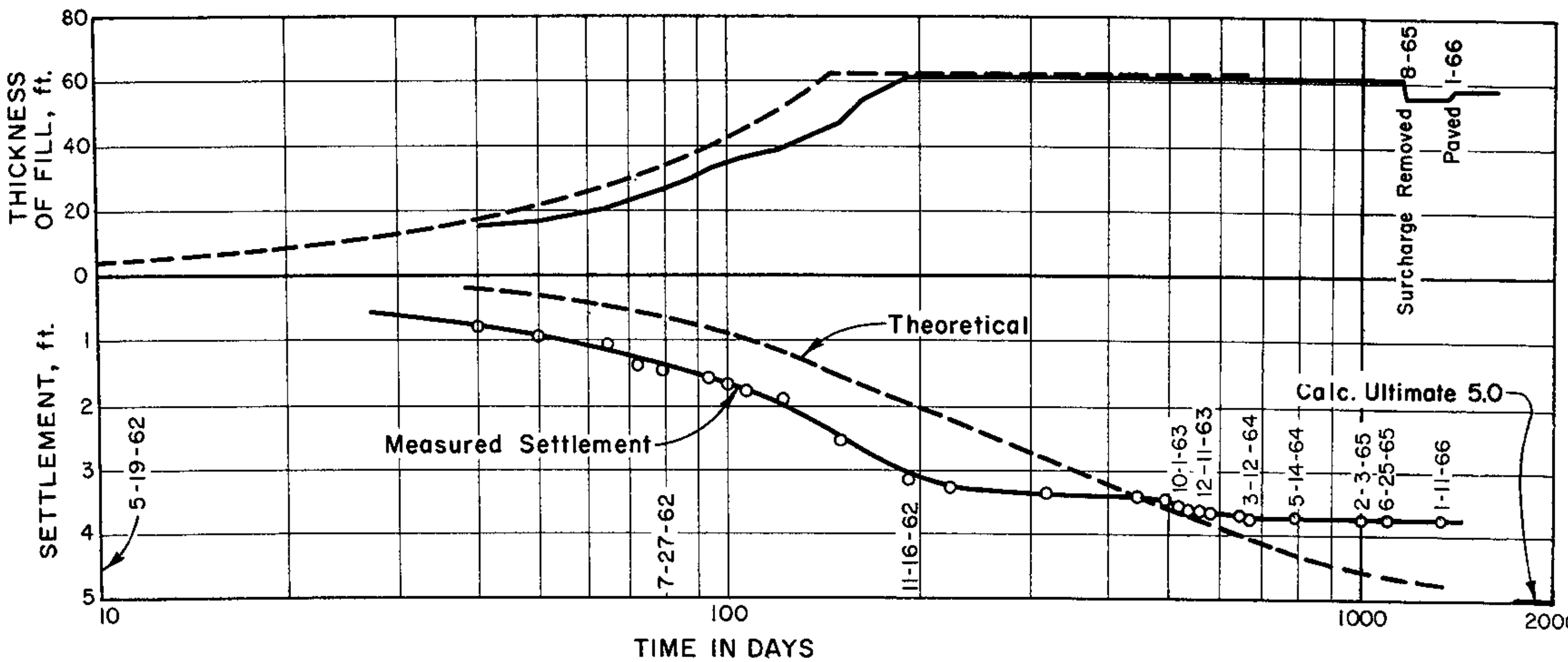


HALF-SECTION SHOWING BERM AND SURCHARGE

SCALE OF FEET
0 40 80

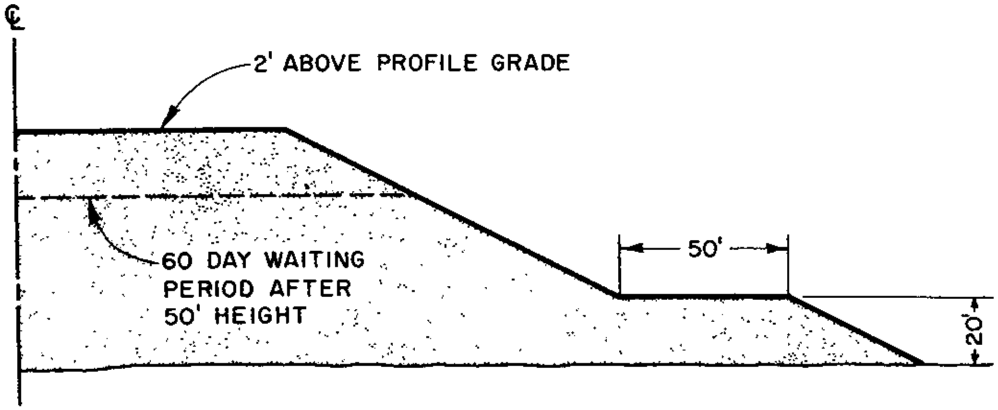
SOIL PROFILE





SETTLEMENT AT SAN DIEGUITO RIVER BASIN
STATION "SD" 1278+50

FIGURE 8

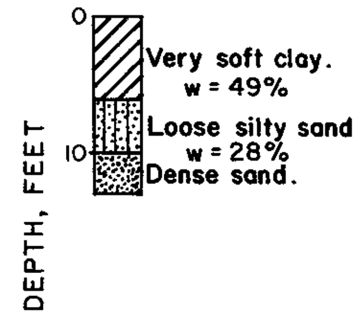


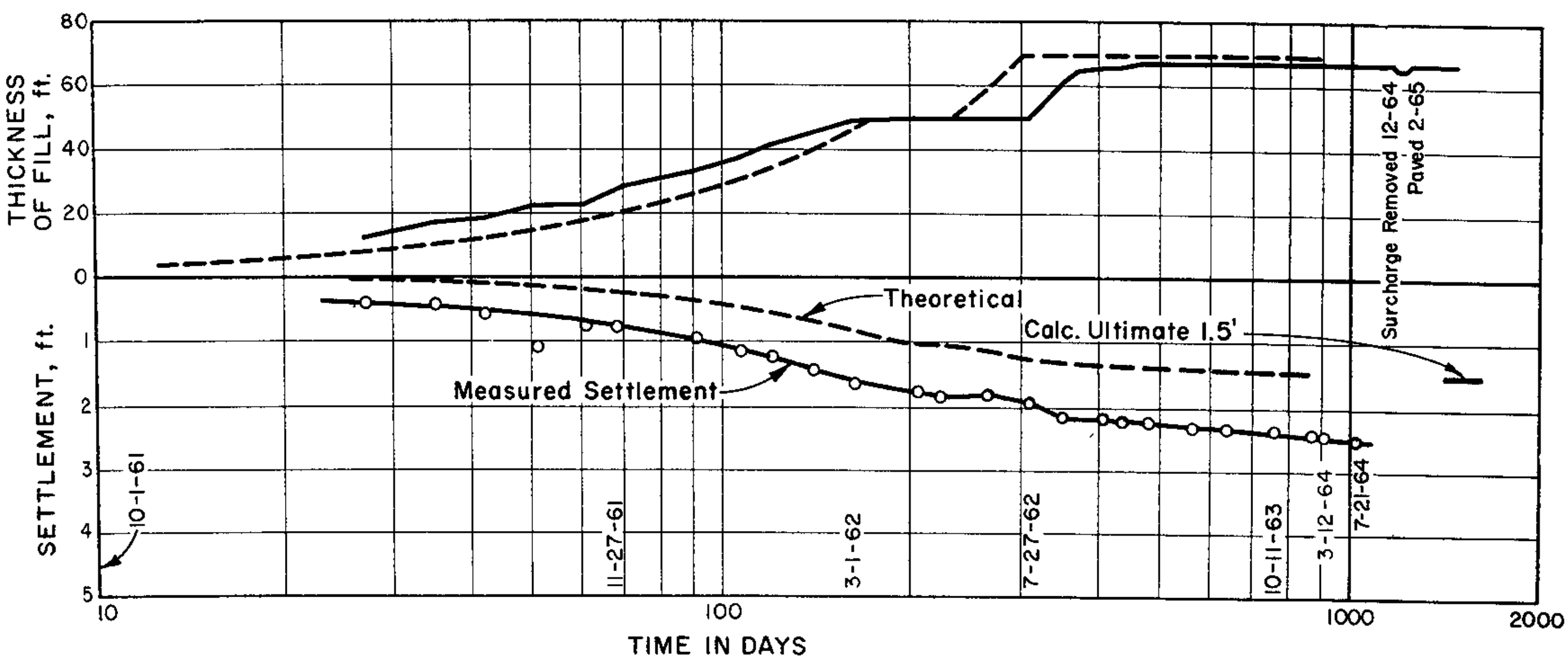
HALF-SECTION SHOWING BERM AND SURCHARGE

SCALE OF FEET

0 40 80

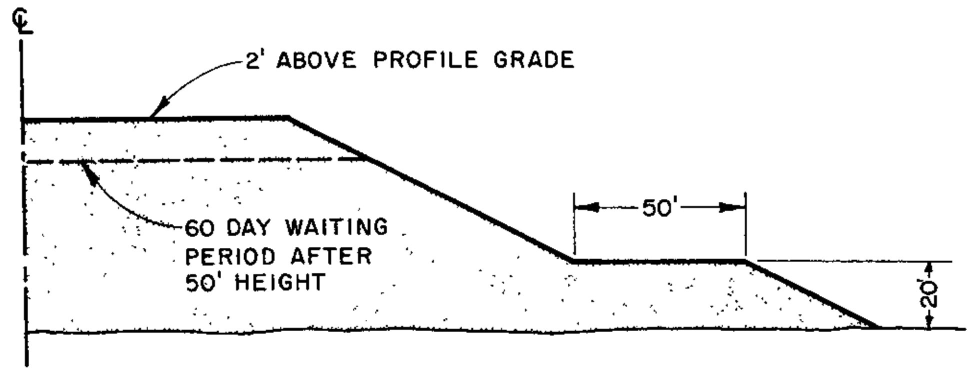
SOIL PROFILE





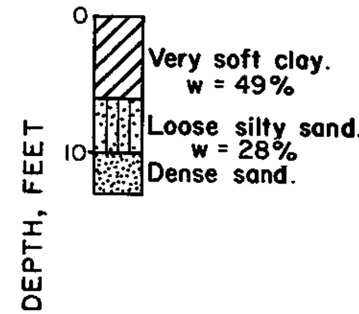
SETTLEMENT AT SAN ELIJO LAGOON
STATION "A" 1383+50

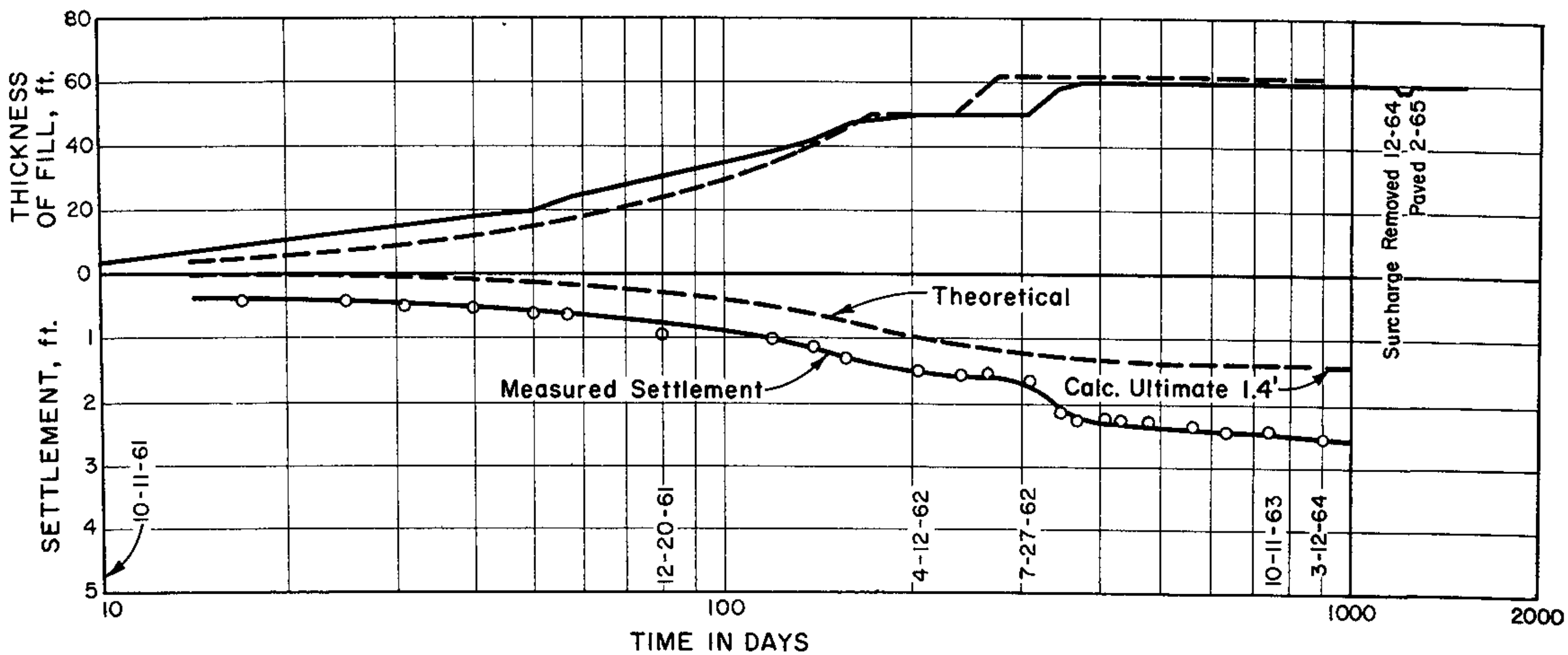
FIGURE 9



HALF-SECTION SHOWING BERM AND SURCHARGE

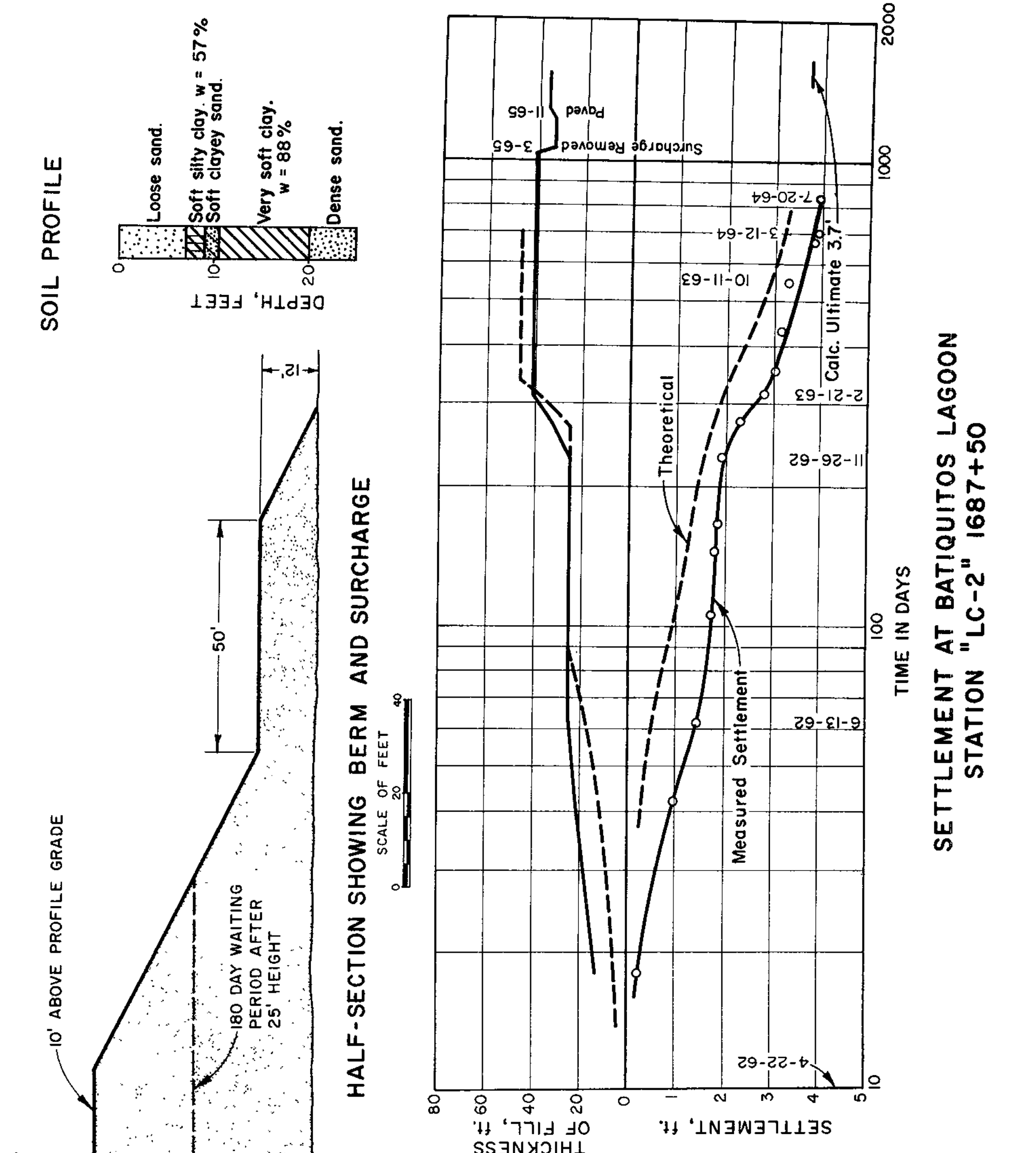
SCALE OF FEET





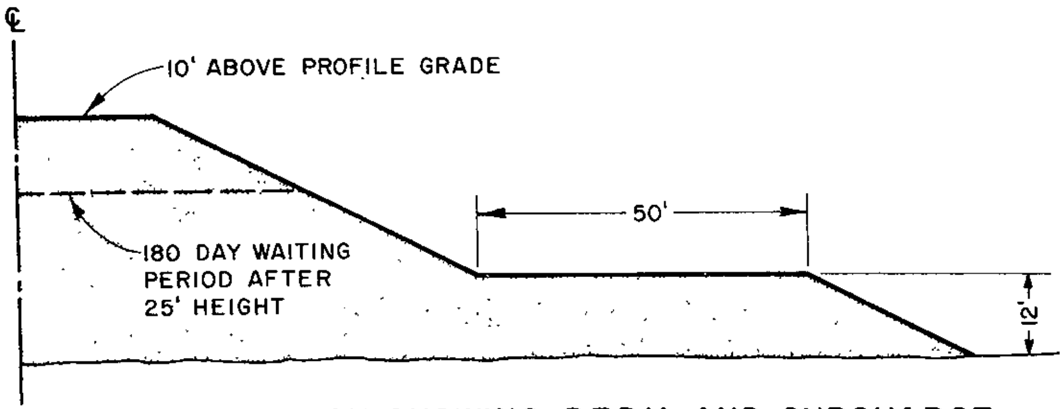
SETTLEMENT AT SAN ELIJO LAGOON
STATION "A" 1386

FIGURE 10



SETTLEMENT AT BATIQUITOS LAGOON
STATION "LC-2" 1687+50

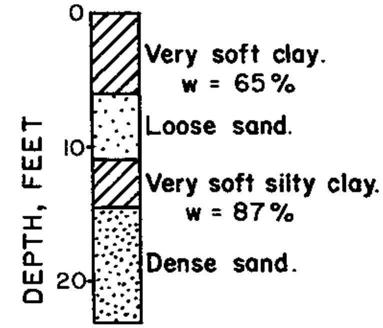
FIGURE 11

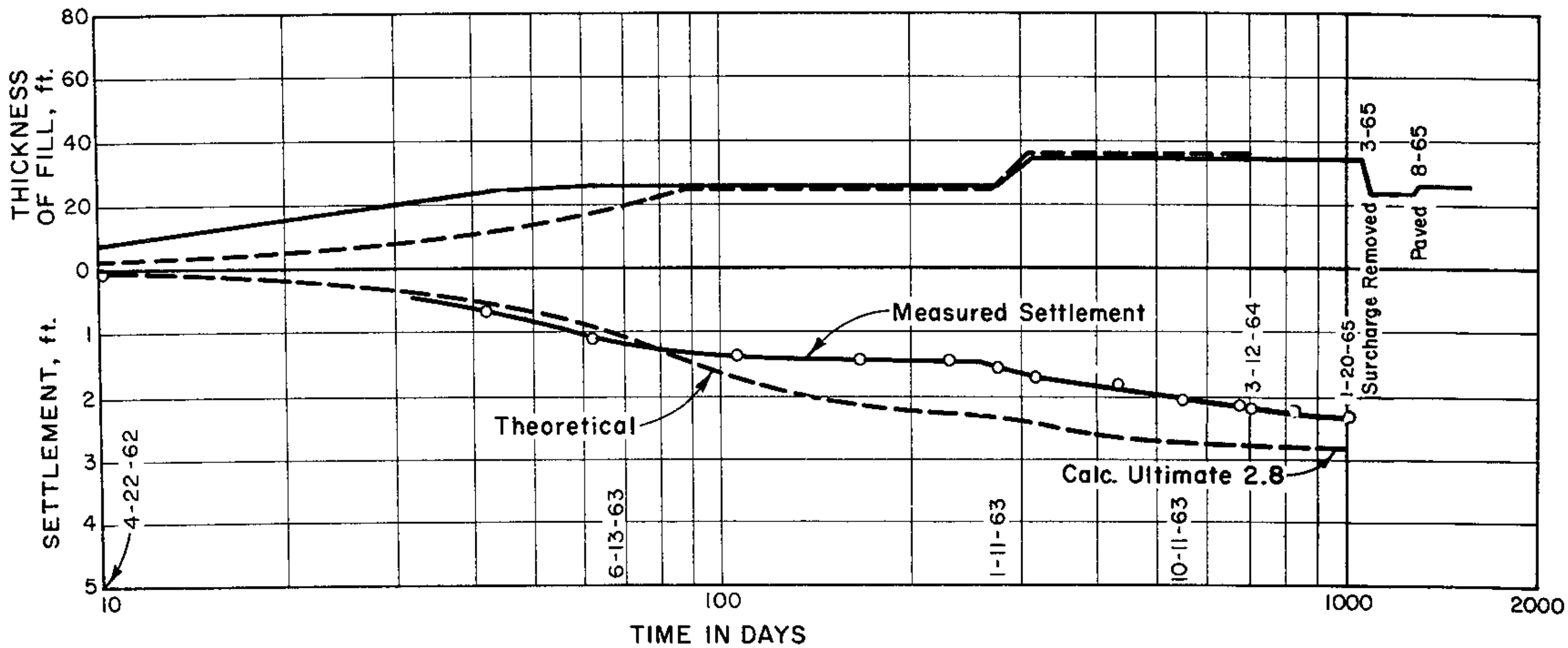


HALF-SECTION SHOWING BERM AND SURCHARGE

SCALE OF FEET 0 20 40

SOIL PROFILE





SETTLEMENT AT BATIQUITOS LAGOON
STATION "LC" 1693+50